ITER Relevance: ELM – Simulating Plasma Gun

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Overview

- Need for a ELM-Simulating Plasma Gun
- Facilities in Other Countries
- ESP-Gun at Illinois
  - Helicon, Pre-ionization Source Plasma
  - Conical Theta Pinch
  - Pulse Forming Network (PFN)
  - Pulses Merged into an ELM
- Data from Phase I
- Scale-up Possible

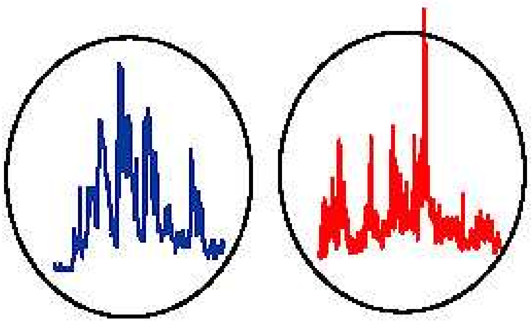
Motivation

- Why study ELMs?
  - Limiting heat flux for divertor surfaces
  - Largest cause of divertor erosion and impurity production
  - How effective is "vapor / plasma shielding" h

- ELM Plasma Material Interactions
  - Test bed for candidate divertor materials
  - Material survivability / erosion / melt layers
  - Surface effects
    - Are there different redeposition rates for mixed materials?
    - Changes in surface morphology and composition?

Type-I ELM Characteristics

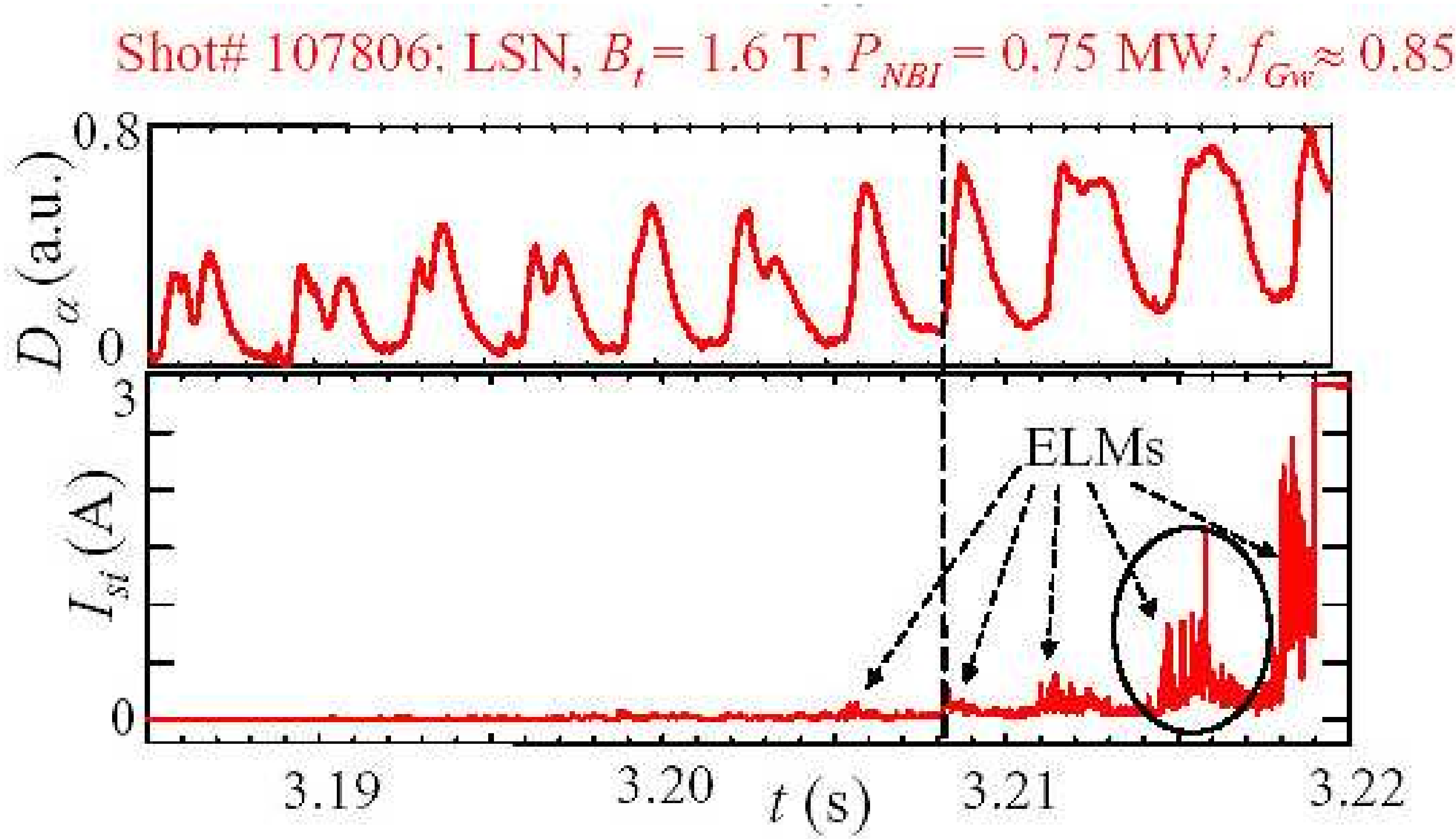
- ELMs emanate from the LCFS
- Higher n_e and T_e at PFC
- An ELM is a series of plasma bursts
  - Each burst is 50 μs
  - Envelope (the ELM) lasts ~1 ms
- Experimental evidence on several machines[1,2]
- High heat flux onto the divertor surface



- To the probe ELMs appear as series of spikes rather than a discrete event as on D_α

[1]C. E. Bush, et al., "ELM Physics in NSTX – Onset and Characteristics", NSTX Research Forum, November 28-30, 2001. Reprinted from ALPS 2003 Meeting, Oakbrook IL.
[2]D. Rudakov, "Far SOL and Near-Wall Plasma Studies in DIII-D," ALPS Meeting November 2003, Oakbrook, IL.

D-IIID data showing ELM structure



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Plasma Guns in Russia

Neither device has the time signature and field of an ELM

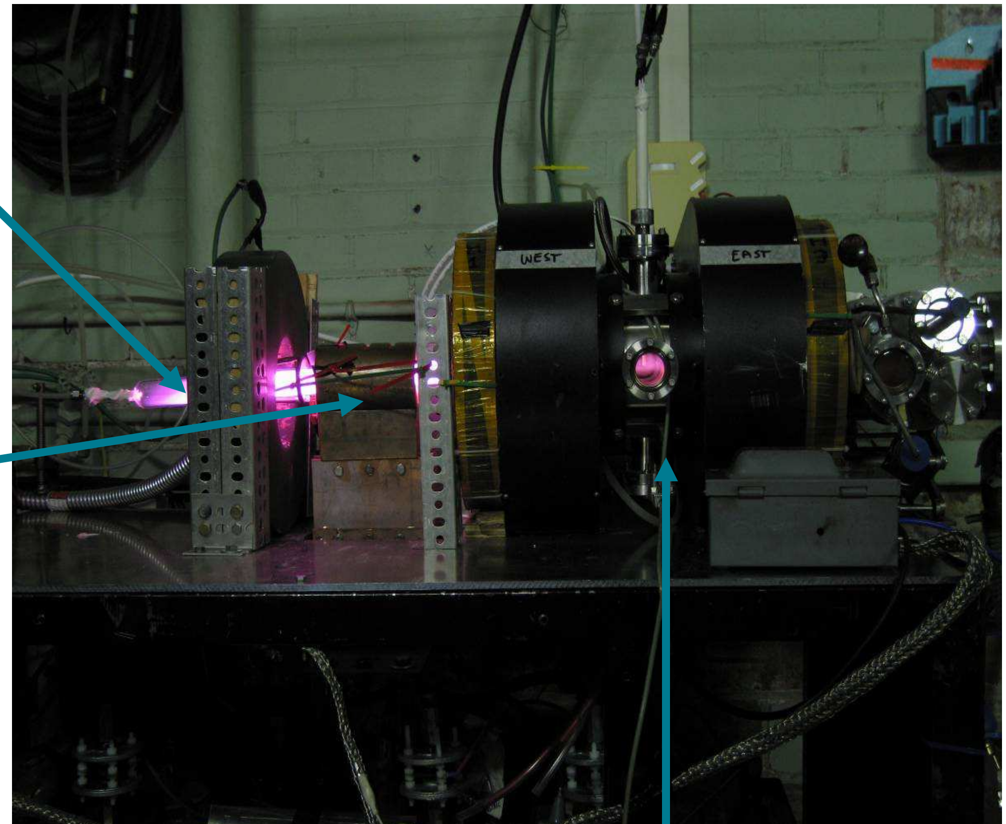
QSPA

Mk-200UG

Heat load (MJ/m^2)	0.5-2	0.2–1
Pulse duration (ms)	0.1–0.6	0.04–0.06
Plasma stream ϕ (cm)	5	6-10
Magnetic field (T)	0	0.5-1.2
Ion impact energy (keV)	<0.1	1.5
Electron temp. (eV)	<10	100-200
Plasma density (m^{-3})	$< 10^{22}$	$(2\text{-}5)\times10^{21}$

ESP-gun at Illinois

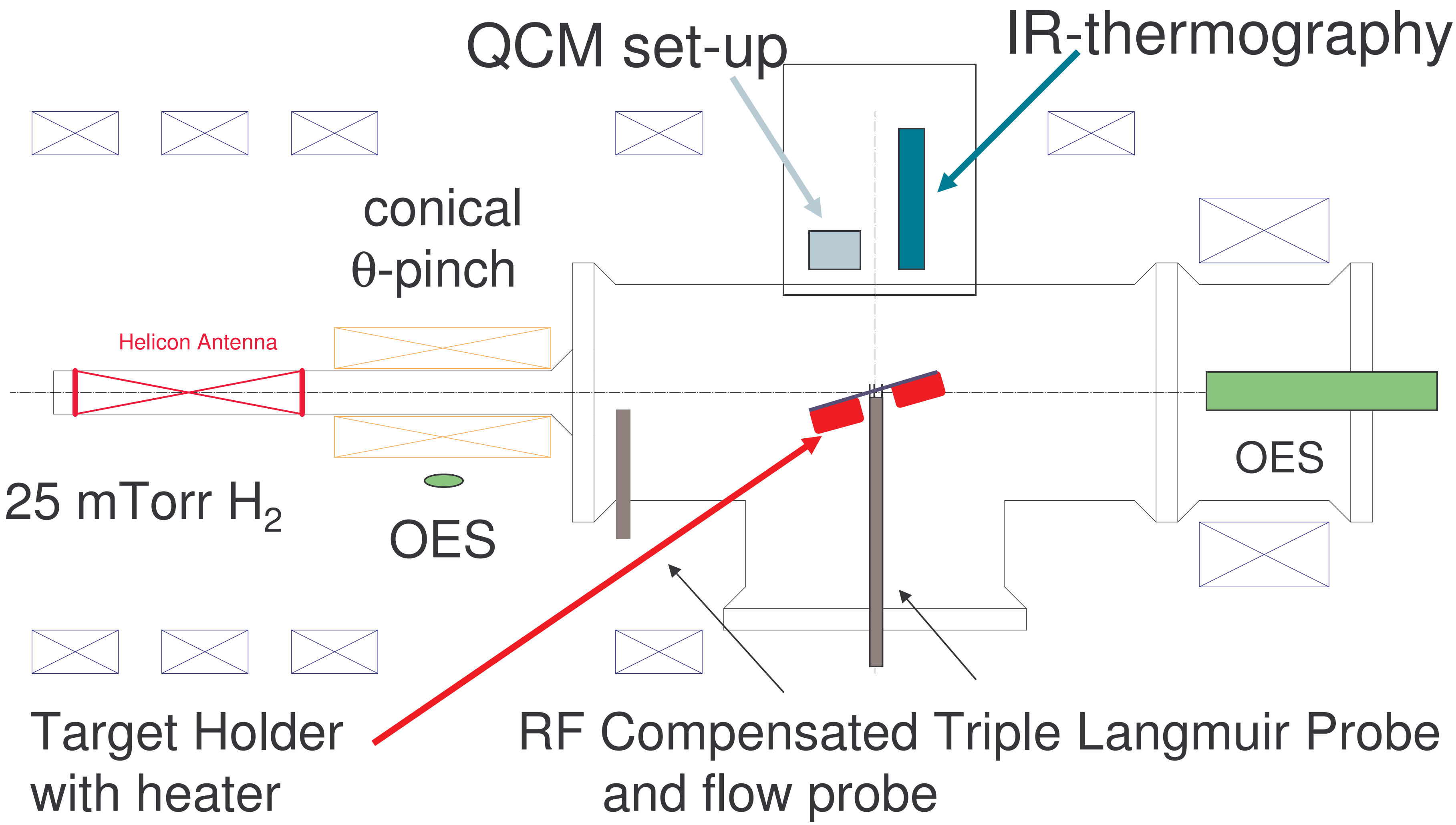
- RF pre-ionization source
- ECR magnets for down stream field
- Conical, theta coil
  - ~ 5º taper

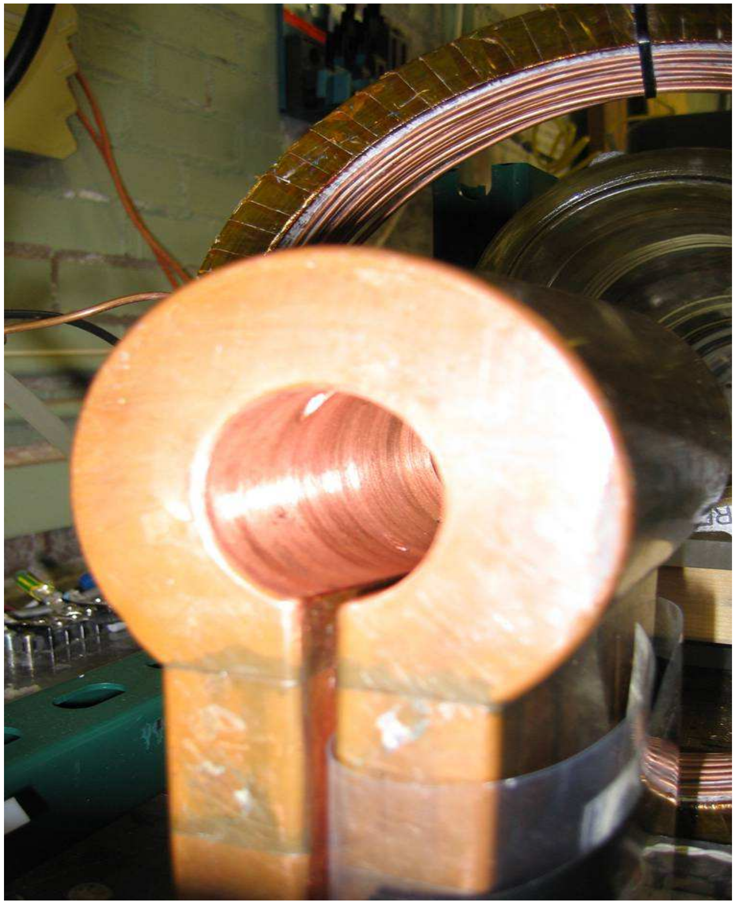


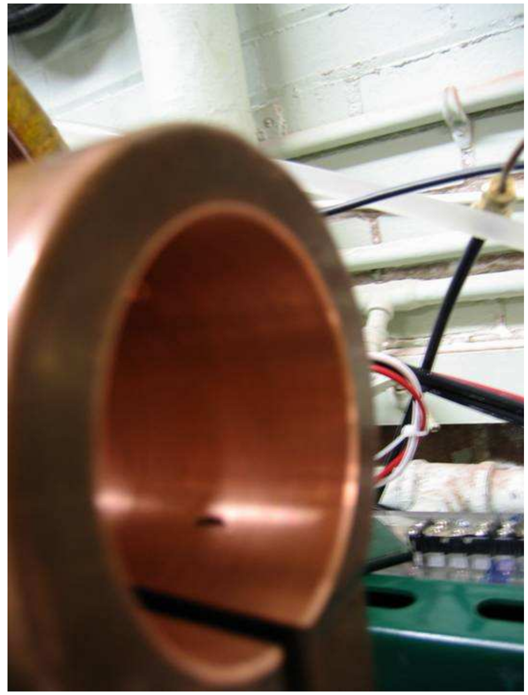
Target Area

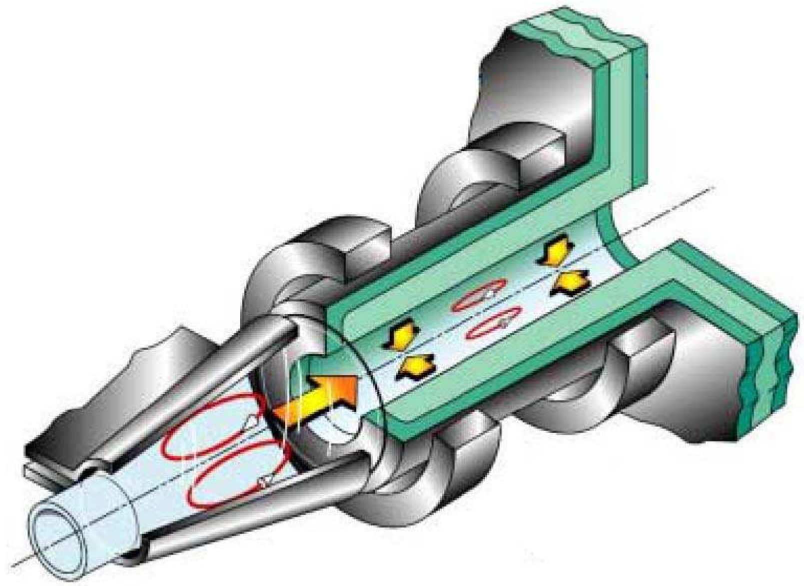
Can provide proper time behavior and B field on target

ESP-gun Diagram





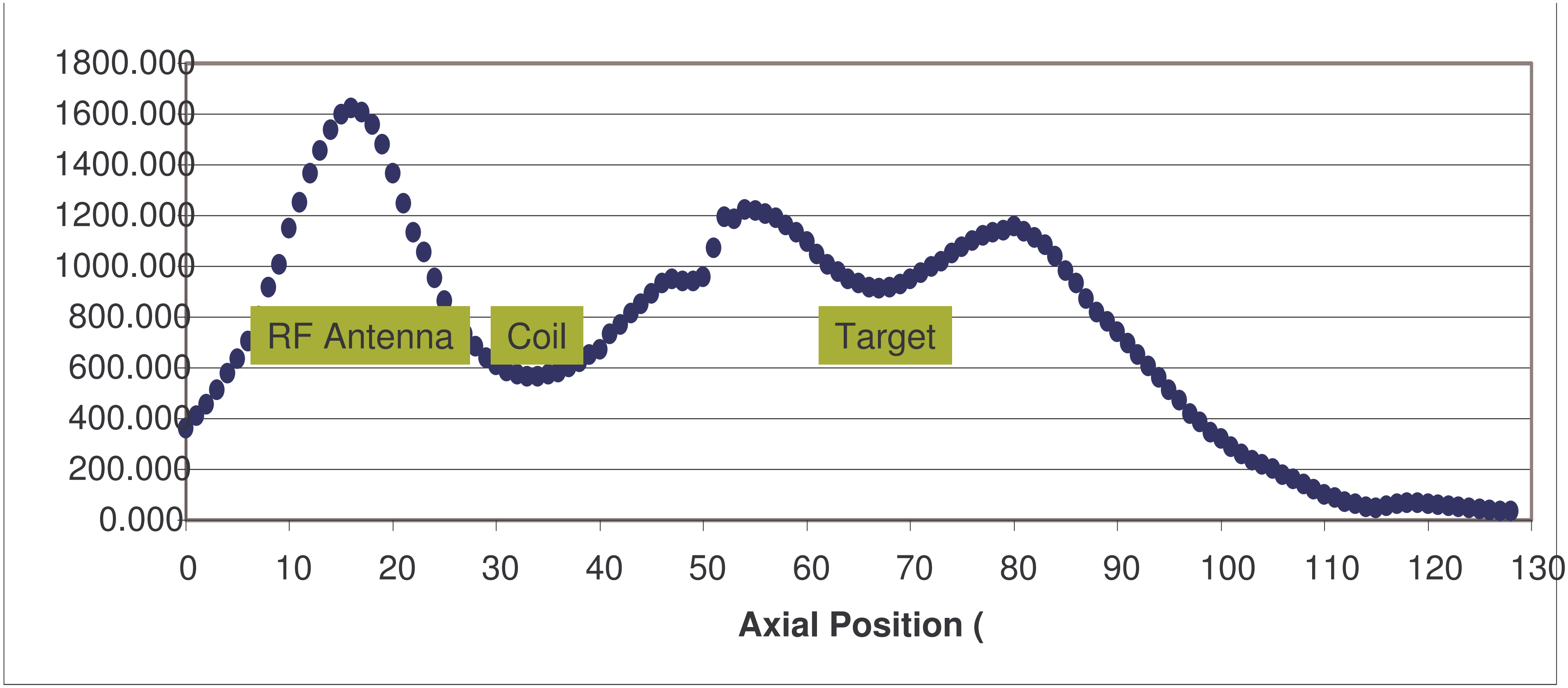




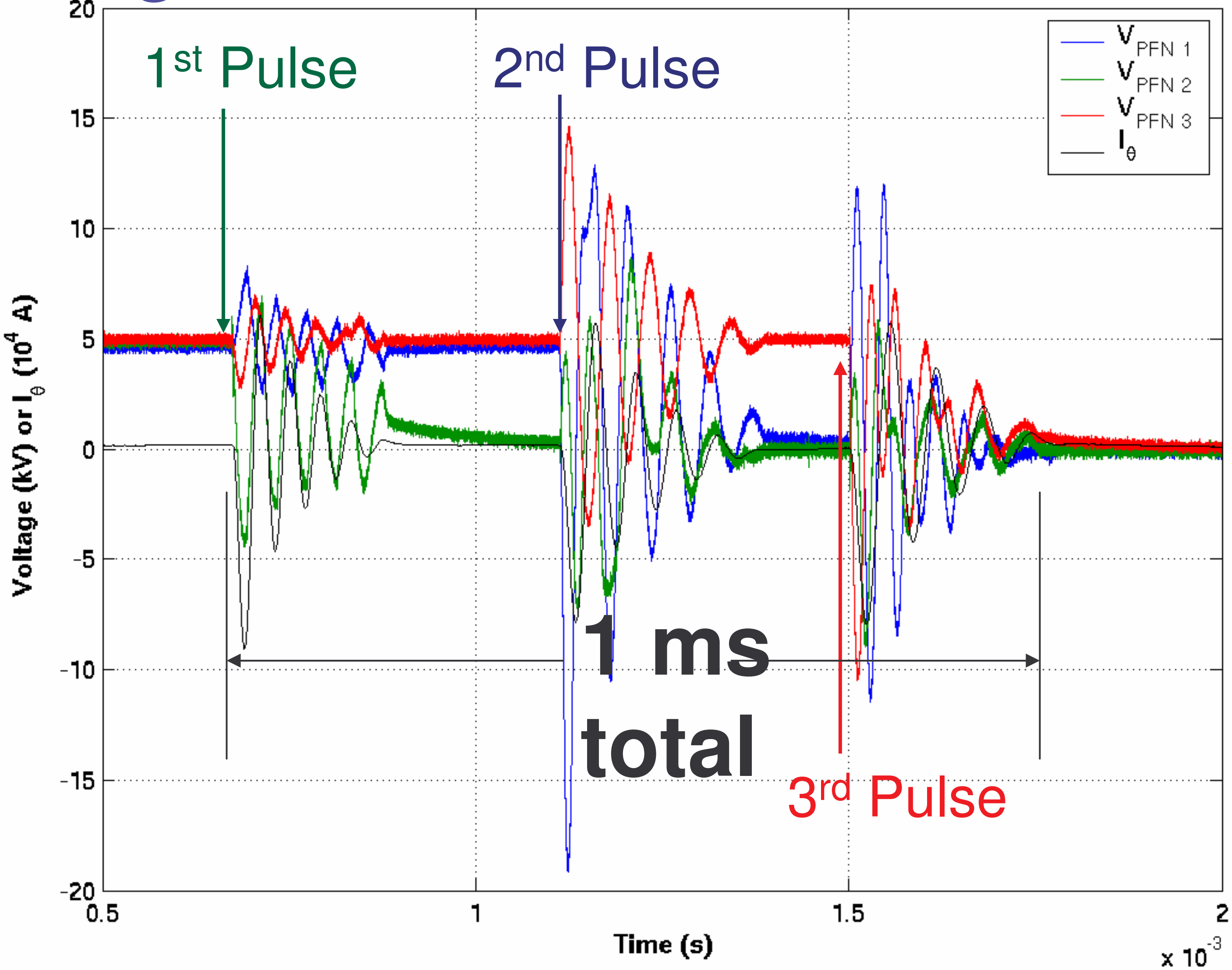
Conical Cross-Section similar to FRC formation / translation

Magnet Field Topology

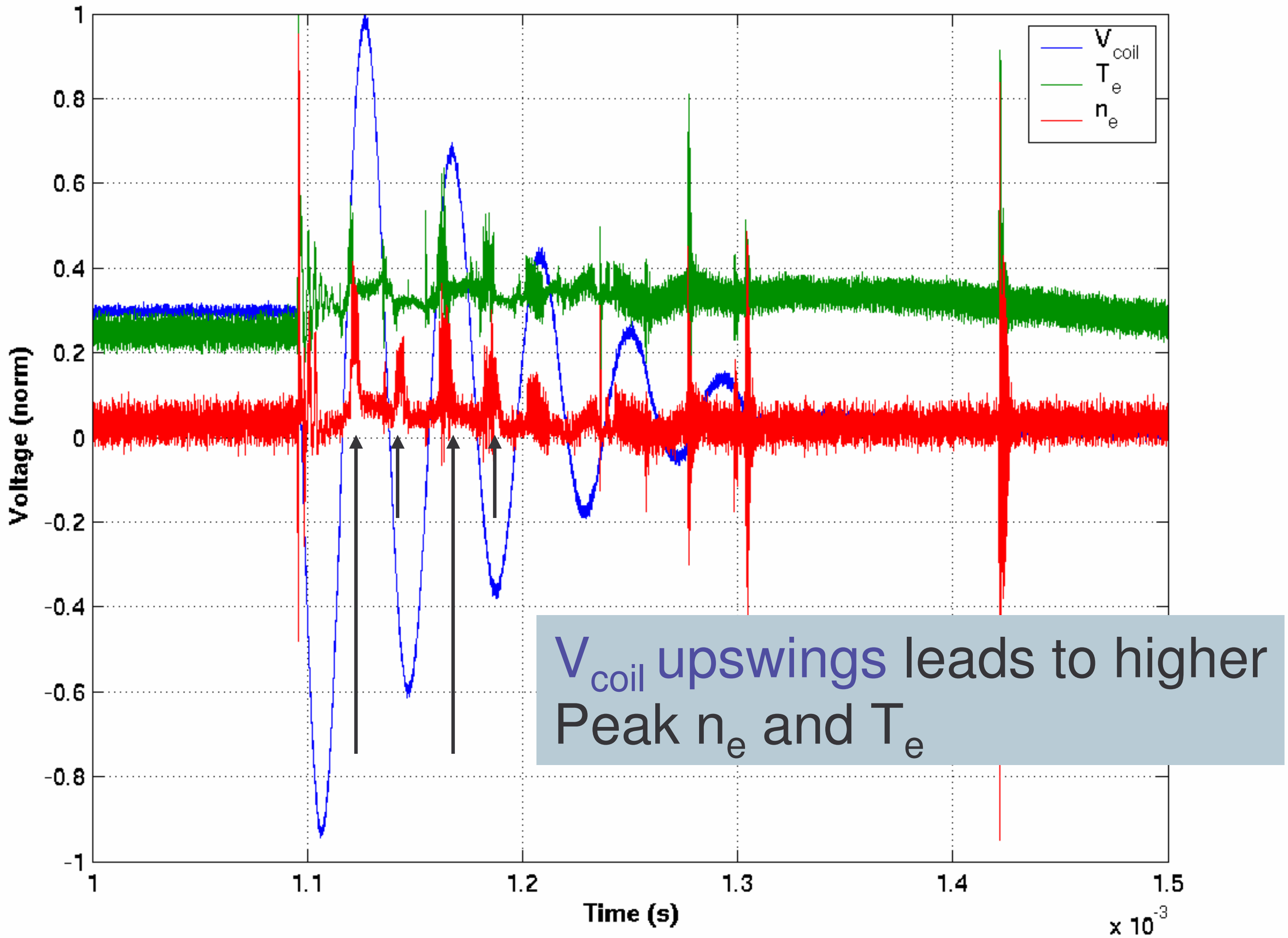
~ 1000 G on target steady state now, can go higher



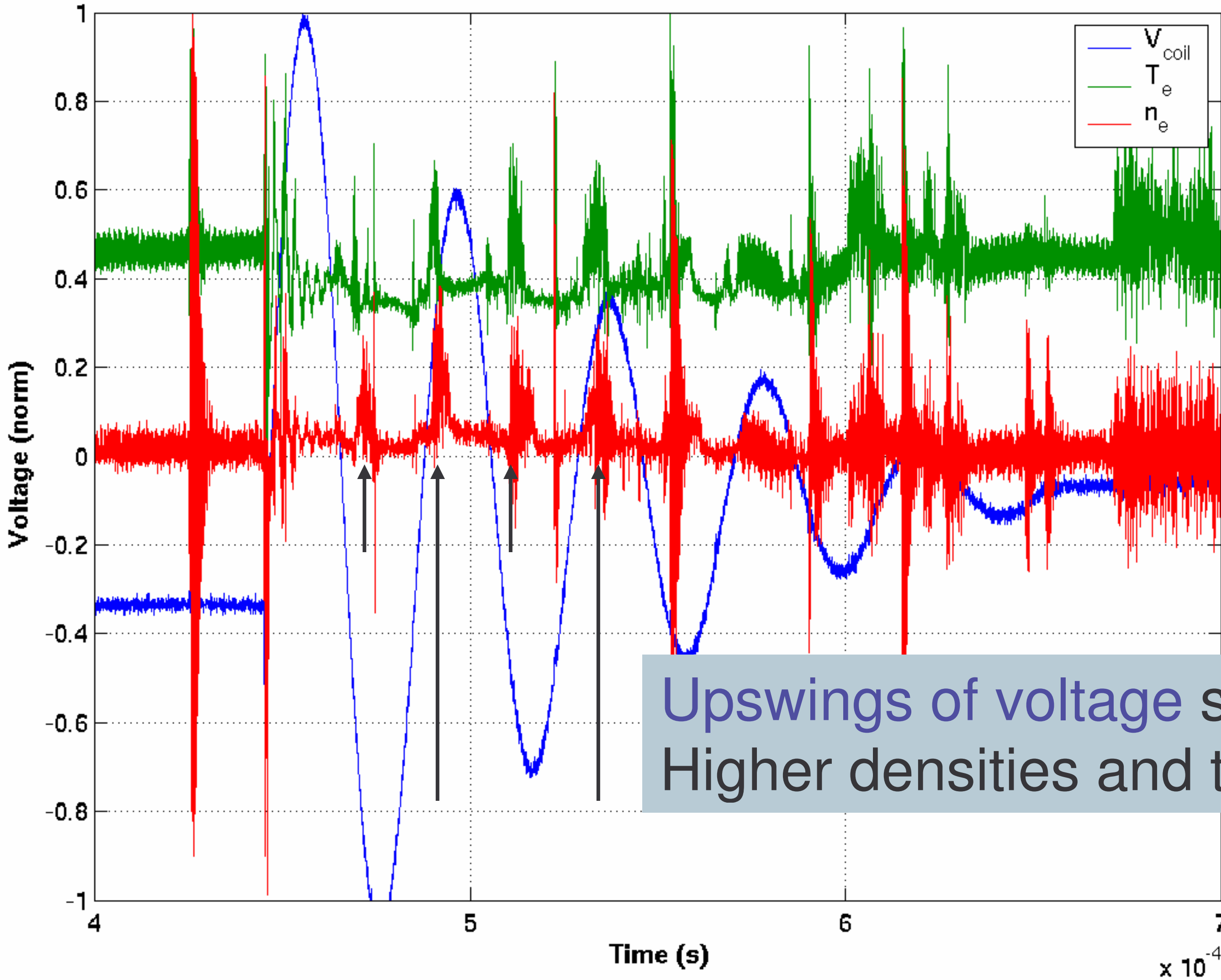
Voltage and Current of Pulse Train



Density and Temperature at Target



Coil fired in opposite polarity



Upswings of voltage still show Higher densities and temperature

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Plasma Pulse Train Behavior

- During upswing of the voltage
  - Higher density and temperatures seen
  - B_{coil} aligned with B_{ext}
  - This should form an FRC since induced current in plasma is opposite guide field.
- During downswing of the voltage
  - Lower density and temperatures seen
  - B_{coil} reversed with respect to B_{ext}
  - No FRC formation possible

Design Goals and Achievements-to-date

- Comparison of anticipated parameters to NSTX (short term) and ITER (long term) for Type-I ELMs

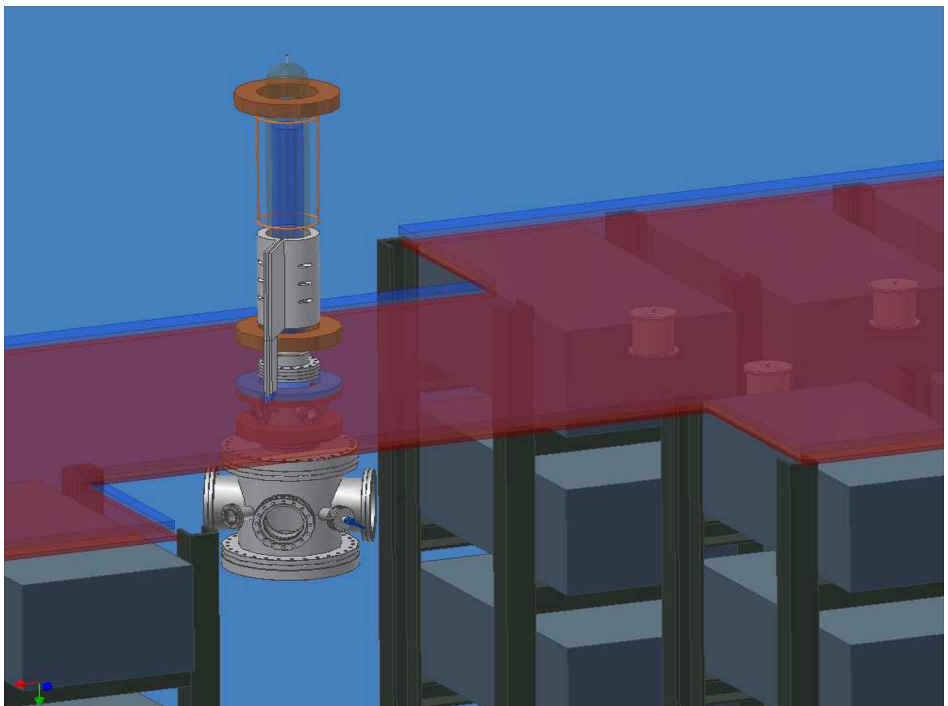
ELM Parameter	ITER	NSTX	UIUC (proposed)	UIUC (present)
Power Loading	~10 MJ/m^2	< 1 MJ/m^2	1 MJ/m^2	10 kJ / m^2
ELM Event Frequency	~1-10 Hz	10-20 Hz	single shot	single shot
Total ELM Duration	~0.1-1 ms	~1 ms	~ 0.5 ms	~1 ms
Blob Subfrequency	~10-100 kHz	~10 kHz	~ 10 kHz	10 kHz
Plasma Temperature During ELM (~$T_{pedestal}$)	1-2.5 keV	100 eV	100 eV	25 eV
Plasma Density During ELM (~$n_{pedestal}$)	~10^{19} m^{-3}	~10^{19} m^{-3}	~10^{19} m^{-3}	~10^{18} m^{-3}
Magnetic Field Strength At Divertor (~B_t	~1-5 T	~0.5 T	0.4 T	0.1 T

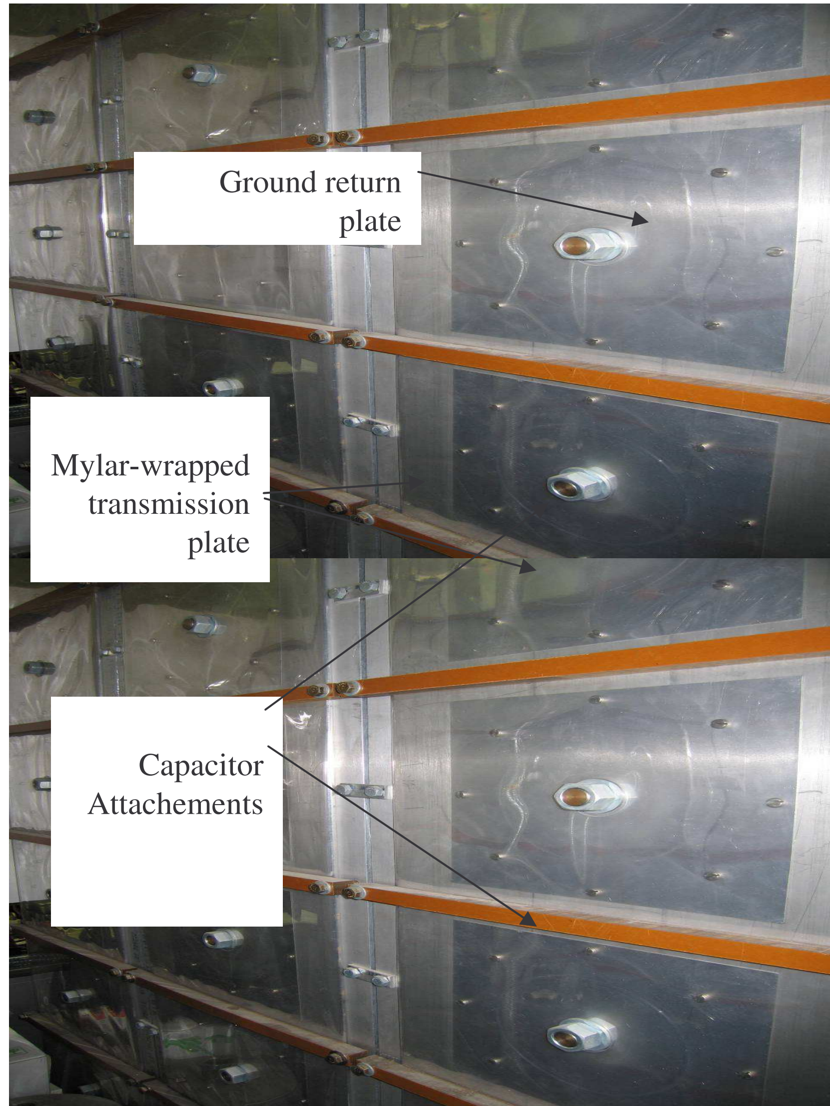
These results, energy input = 0.6875 kJ

For Phase II, 250.0 kJ available --- 300+ times more energy

Phase II Upgrades

- Much **more power** from 250 kJ capacitor bank which has lower inductance capacitors
- **Higher field** from higher current through magnets (could go to pulsed configuration if needed)





Benefit to US PFC Program

- Adds capabilities (field on target, time length and structure of ELMS) **not present internationally**
- **Domestic experiment** directed by US program, directly relevant to ITER tasks
- Compliments Steady-State Plasma exposure device – **PISCES**
- Compliments Electron-Beam High Heat Flux experiment – **Sandia Albuquerque**
- Provides experimental test-bed for HEIGHTS package – **Argonne National Laboratory**

Other Illinois Activities

- Ion – surface interaction fundamental data especially at high temperatures and for liquid metals
- Retention, recycling and plasma interactions with flowing liquid metals
- MD and other modeling of basic PMI issues